Spotting Hidden Sectors with Higgs Binoculars

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Higgs Couplings 2019
Oxford, UK

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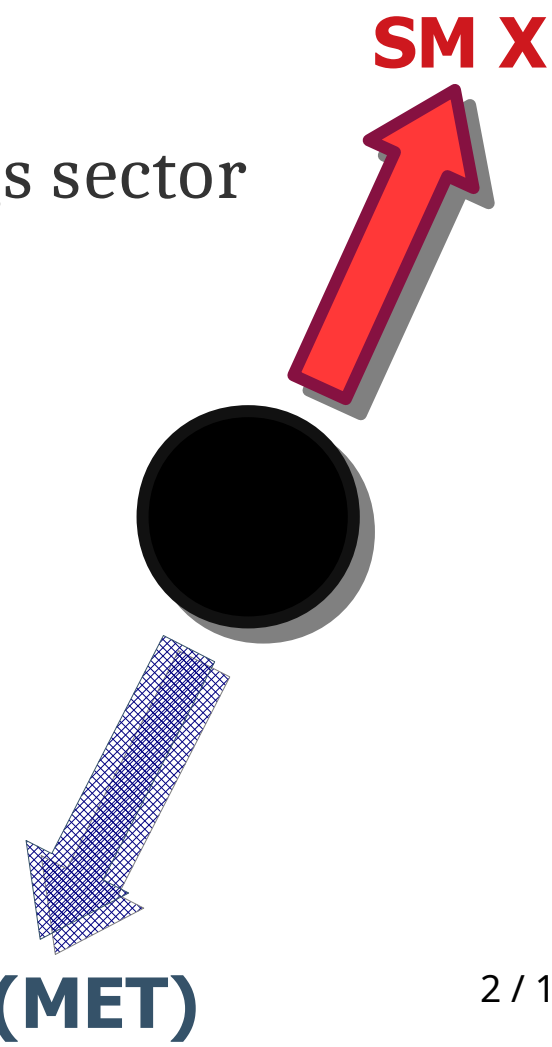
ArXiv:1901.07558 M. Blanke, S. Kast, **J.T**, S. Westhoff, J. Zurita

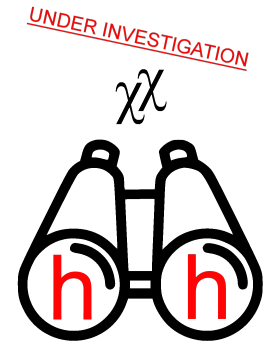
Motivation

- Higgs sector opens up new search options
  - Good place to look for new physics
- Introduce new particles coupled to Higgs sector
- Many mono-X searches
  - j+MET, H+MET, Z+MET arXiv:1810.09420 [hep-ex]
  - We consider **HH+MET**
- Future HL-LHC: 13 TeV, 3 ab^{-1}
  - Chance to find rarer processes



Existing HH+MET searches (SUSY)
arXiv:1709.04896 [hep-ex]
arXiv:1806.04030 [hep-ex]

Model Lagrangian and Details



Add 2 new scalars to the SM:

Effective coupling to visible sector (via B)

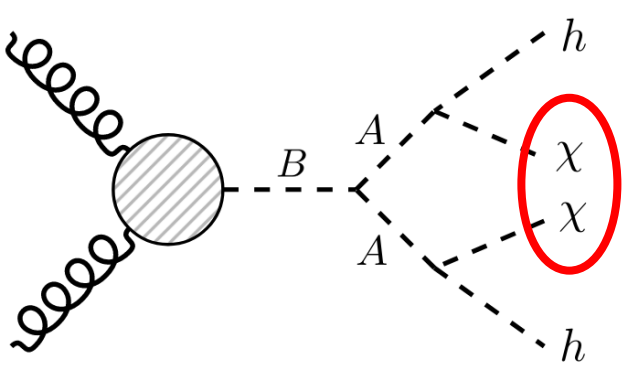
$$\mathcal{L} \supset \frac{C_{Bgg}}{\Lambda} B G^a_{\mu\nu} G^{\mu\nu\, a} + \frac{m_{BAA}}{2} BAA.$$

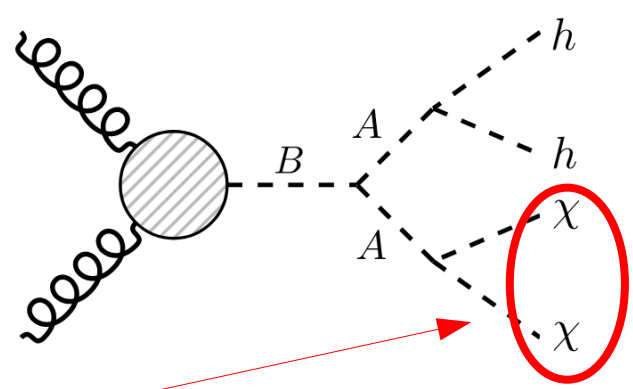
Decay to new scalars (A)

Add decays to SM particles and missing energy:

$$\mathcal{L}_S \supset \lambda_{A\chi HH} A\chi H^\dagger H$$

$$\mathcal{L}_R \supset m_{AHH} A H^\dagger H + \frac{m_{A\chi\chi}}{2} A\chi\chi.$$



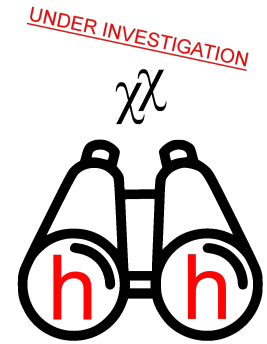


Missing Energy

symmetric

resonant

Model Lagrangian and Details



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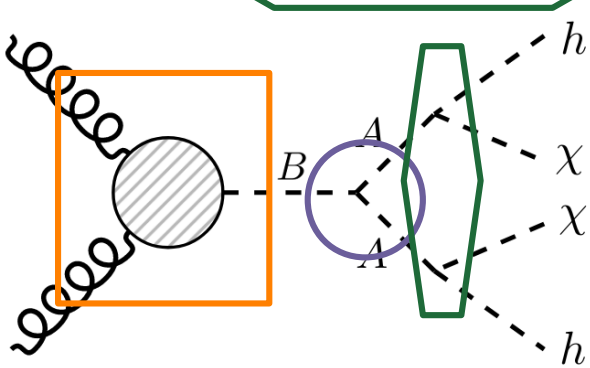
$$\mathcal{L} \supset \boxed{\frac{C_{Bgg}}{\Lambda} B G^a_{\mu\nu} G^{\mu\nu\, a}} + \frac{m_{BAA}}{2} BAA.$$

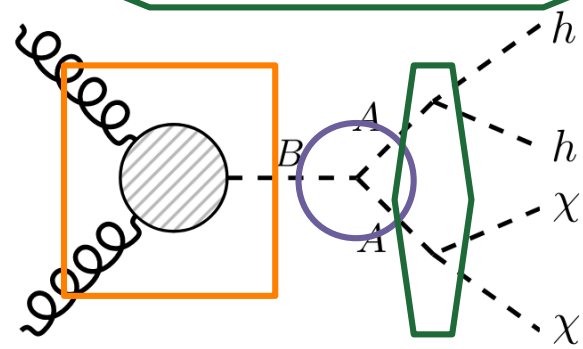
Add decays to SM particles and missing energy:

$$\mathcal{L}_S \supset \lambda_{A\chi HH} A\chi H^\dagger H$$



symmetric

$$\mathcal{L}_R \supset m_{AHH} AH^\dagger H + \frac{m_{A\chi\chi}}{2} A\chi\chi.$$



resonant

Can χ be Dark Matter?

Stable: impose $\mathbb{Z}_2$ symmetry

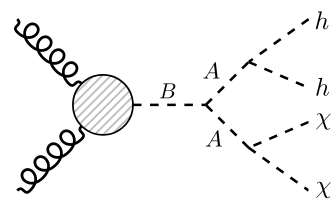
h-χ mixing after EW-breaking
Set mixing angle = 0

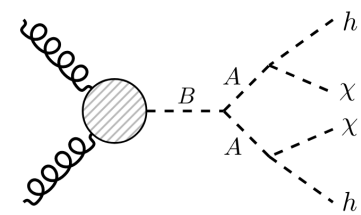
resonant

symmetric

$$\mathcal{L} = \frac{C_{Bgg}}{\Lambda} B G^a_{\mu\nu} G^{\mu\nu\, a} + \frac{m_{BAA}}{2} BAA + m_{AHH} A H^\dagger H + \frac{m_{A\chi\chi}}{2} A\chi\chi + \lambda_{A\chi HH} A\chi H^\dagger H.$$

h-A mixing after EW-breaking
- Strong DD bounds
- Here: relative size is important
- **Set both m_{AHH} and $m_{A\chi\chi}$ small**





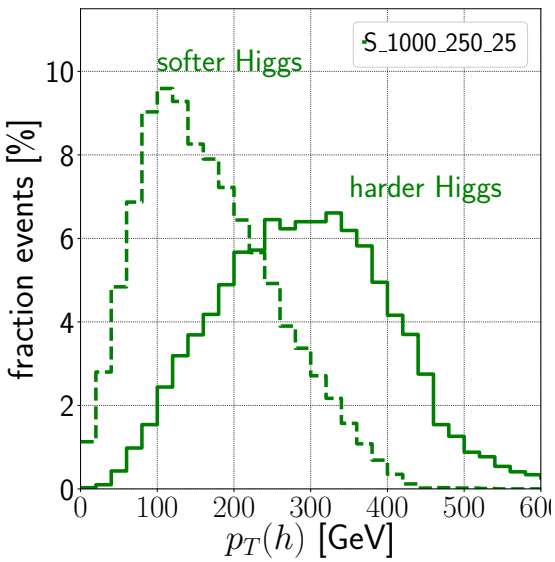
Thermal relic?

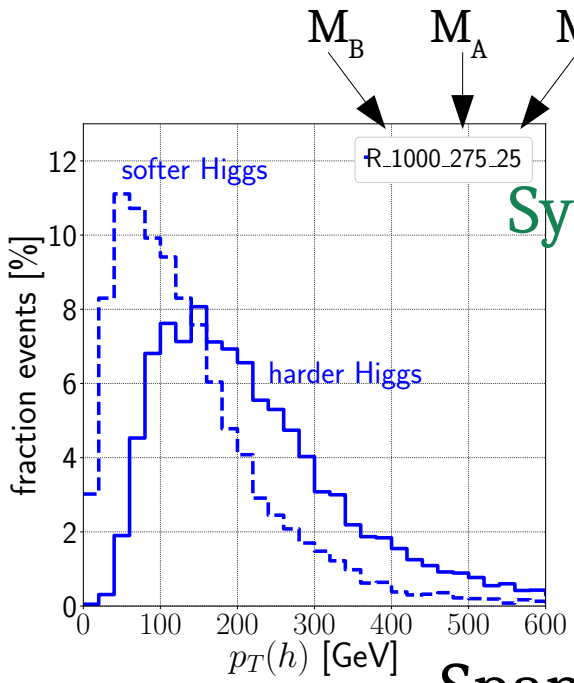
$2M_\chi \approx M_H$

$2M_\chi \approx M_H$
$M_\chi > M_H$

Note: If unstable, χ could decay outside the detector
→ Could be detected by FASER, MATHUSLA

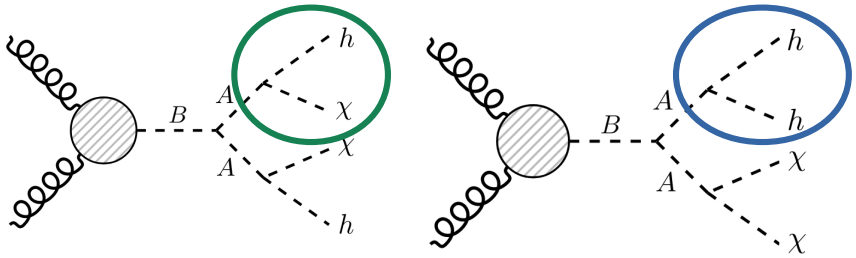
Signal Kinematics



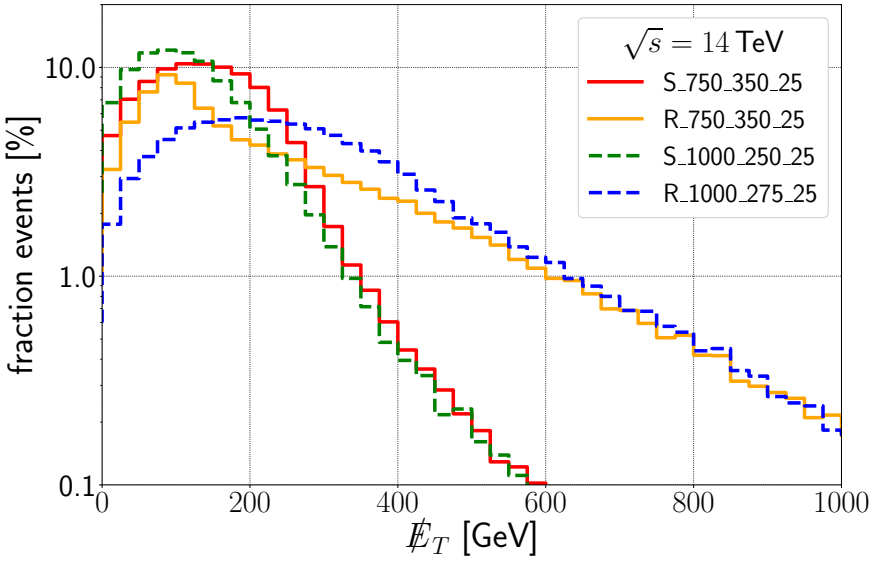


Higgs boson p_T:

Symmetric harder than resonant



Spans boosted to ~resolved regime



- Kinematics driven by splitting
  - M_B-$2M_A$, M_A-(M_H+M_χ)
  - M_B-$2M_A$, min(M_A–$2M_H$, M_A-$2M_\chi$)
- MET harder in resonant
  - Aligned with parent A

Search Strategy

- Focus on HH decay to 4 b
- Background: V+jets, $t\,\bar{t}$
- Make use of signal features
  - Multiple b-jets
  - Large MET
  - No leptons
  - 2 Higgs boson resonances
- 200 GeV MET cut (triggering)
- 2 Higgs candidates:
  - 2 fat jets each b-tagged
  - Higgs mass window?
- Use a Boosted Decision Tree

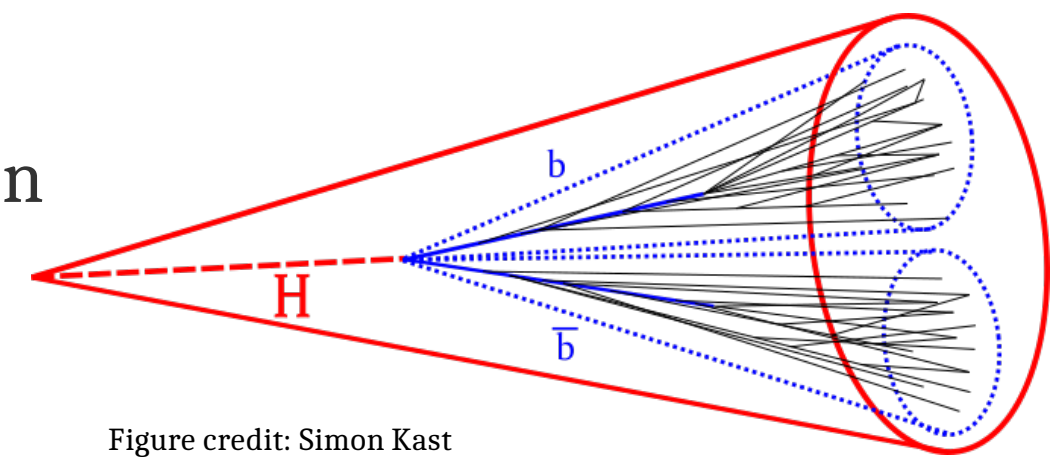
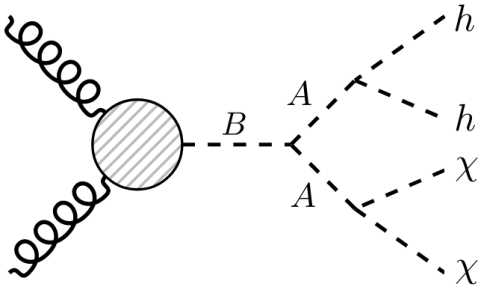


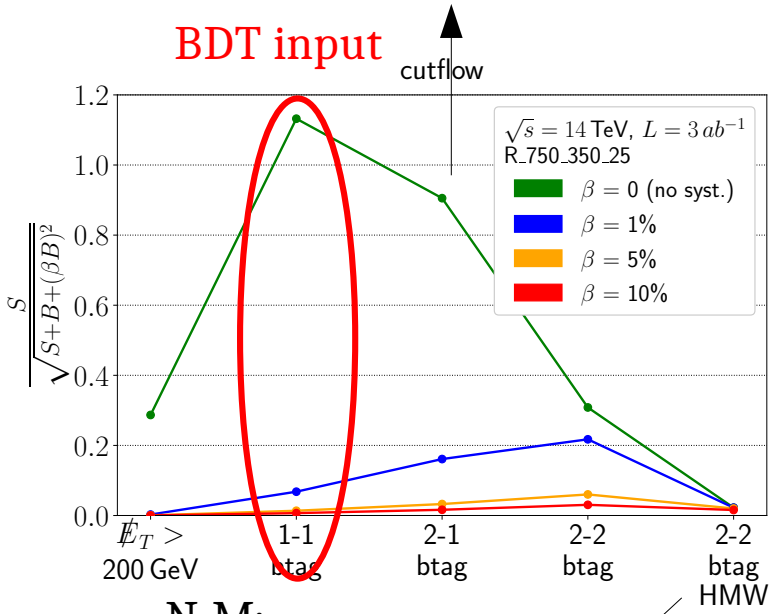
Figure credit: Simon Kast

Resonant Model



Cut flow based on signal features

More b-tags reduces significance

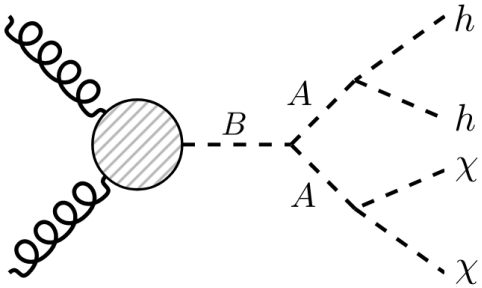


N-M:

- 2 fat jets (R=0.6)
- N, M b-tagged subjets

Higgs mass window hurts us

Resonant Model



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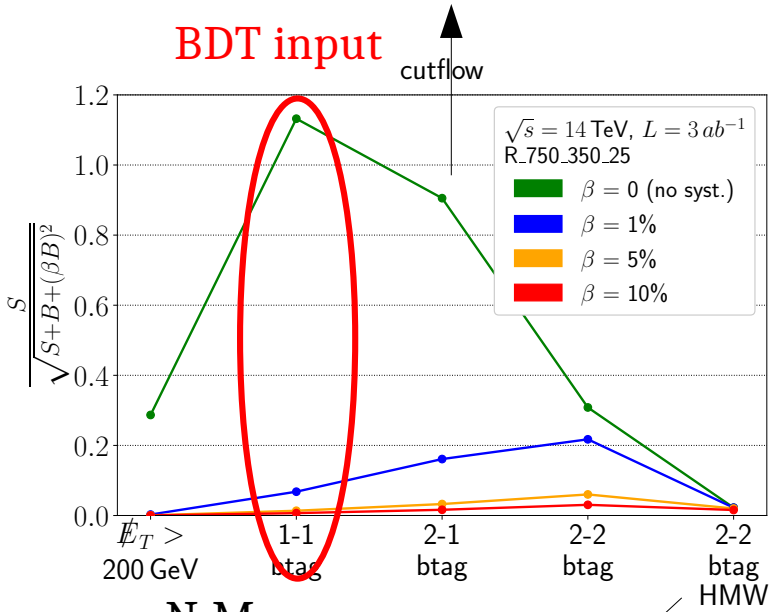
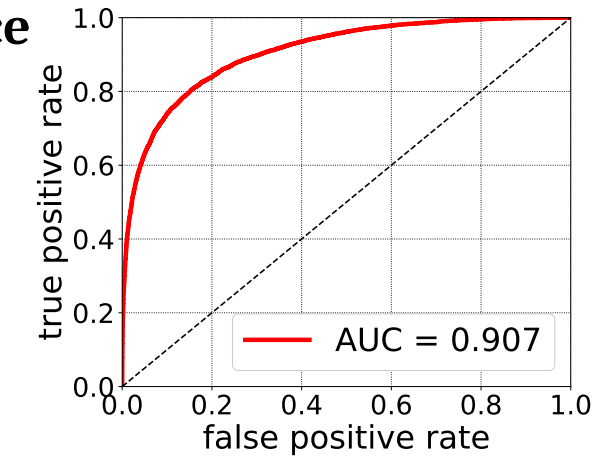


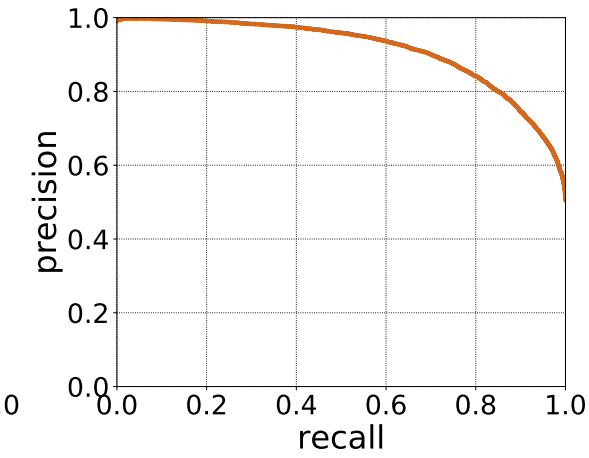
N-M:

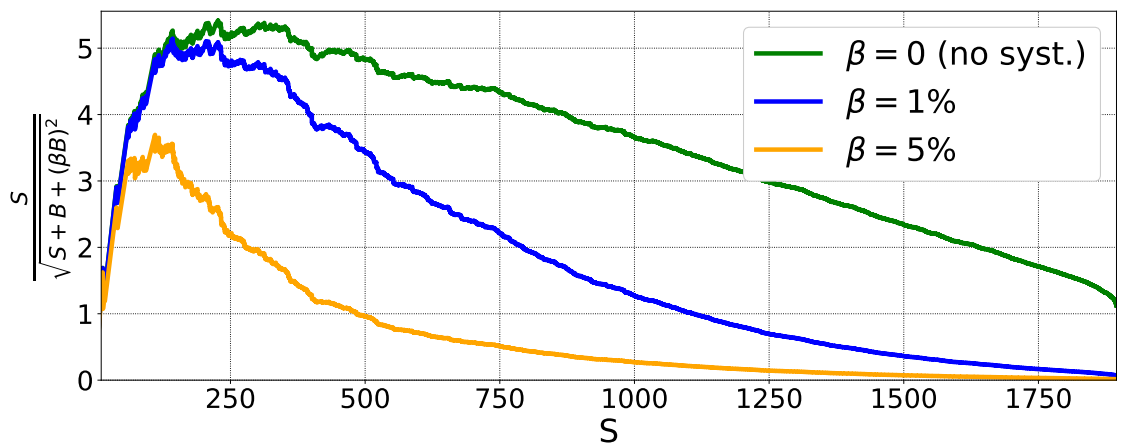
- 2 fat jets (R=0.6)
- N, M b-tagged subjets

Higgs mass window hurts us

BDT gives much better sensitivity

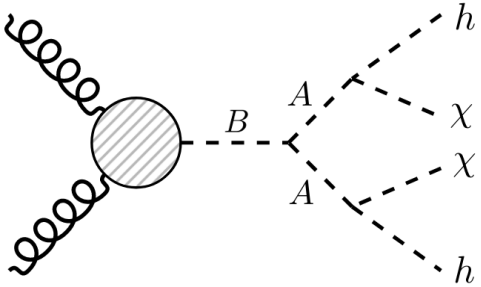






$> 3\,\sigma$ at 5% systematics

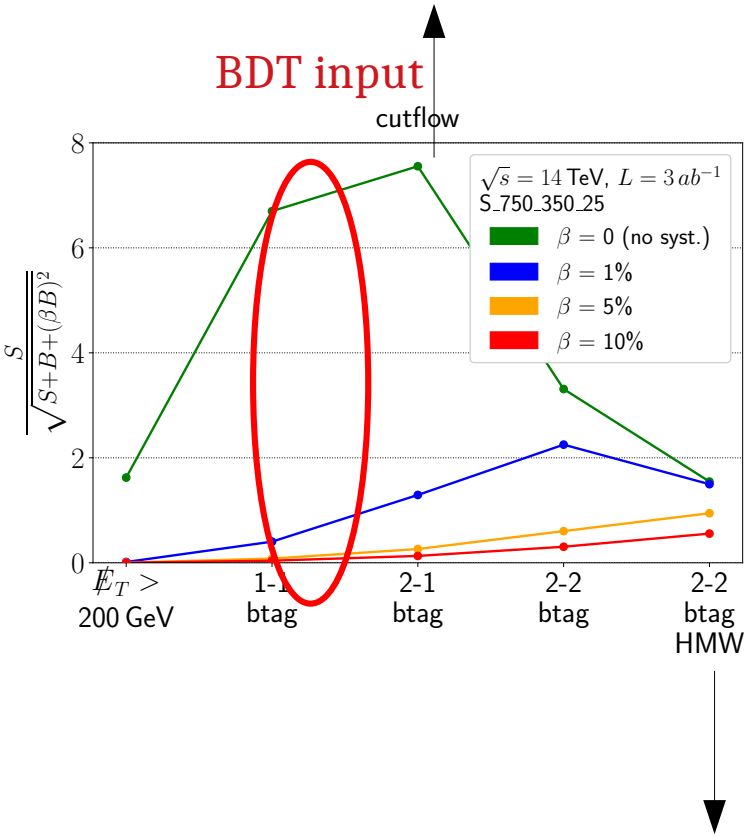
Symmetric model

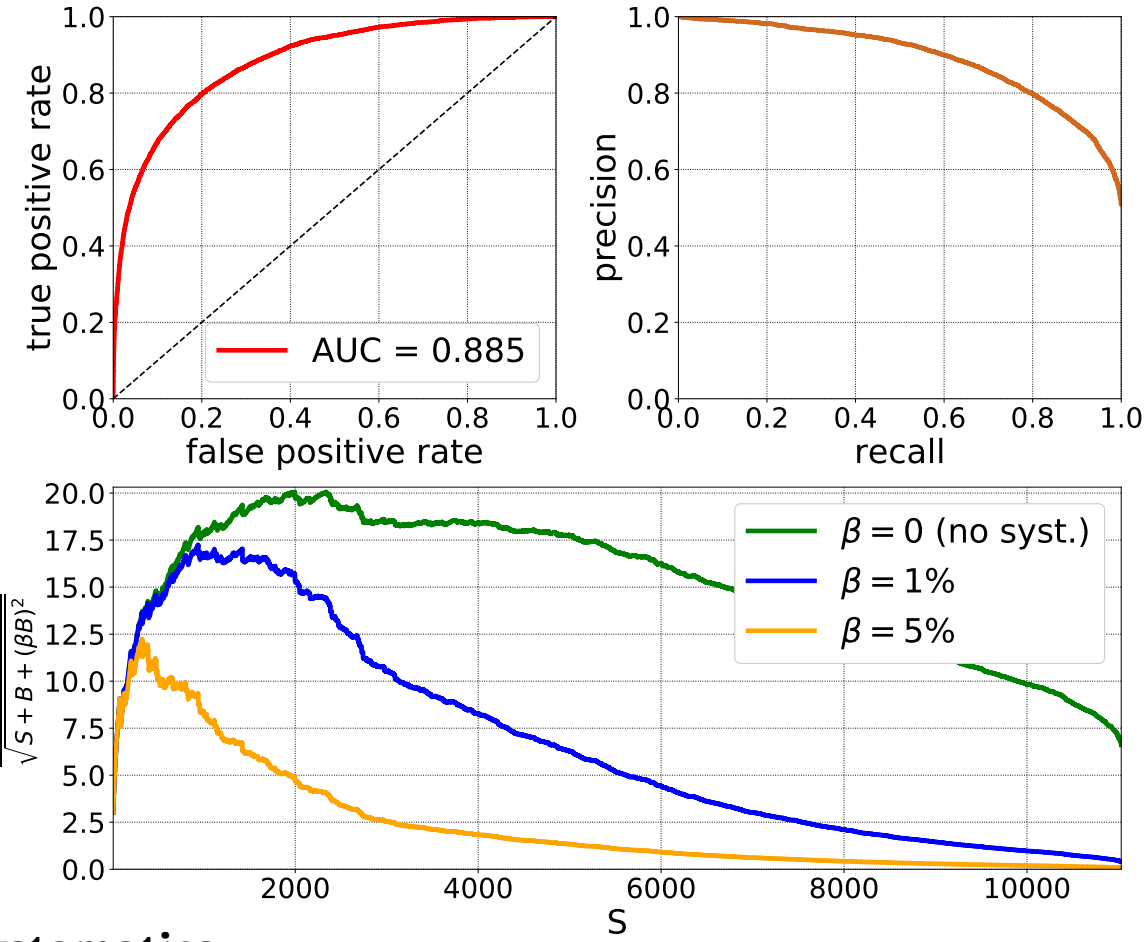


Fat jets R=1.2

More b-tagged subjets

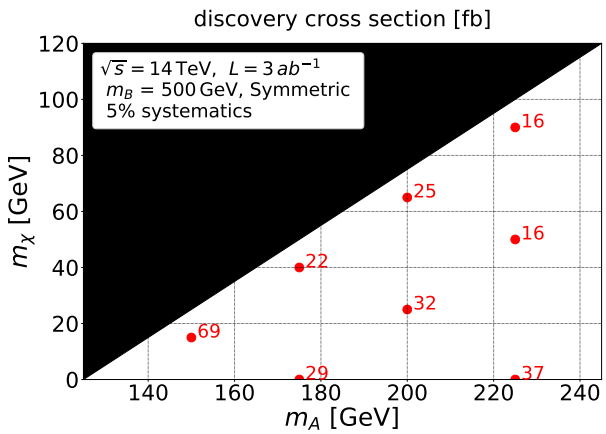
BDT input

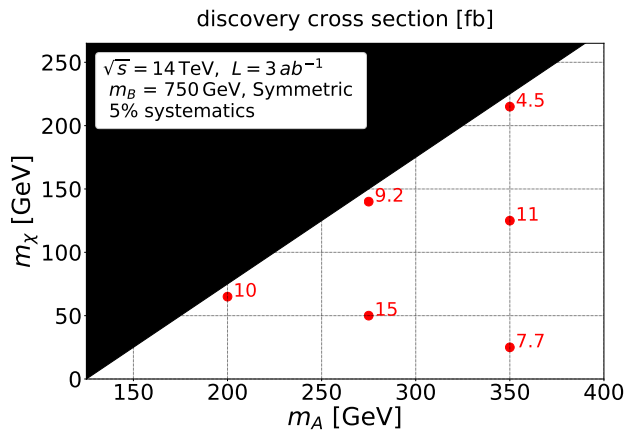




Higgs mass window good for larger systematics

Discovery Cross Sections



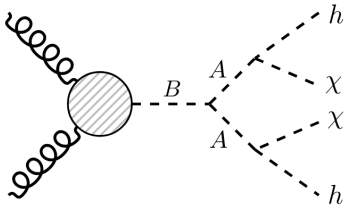


Could be visible at the HL-LHC

Symmetric

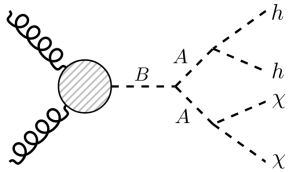
Smaller required cross section:

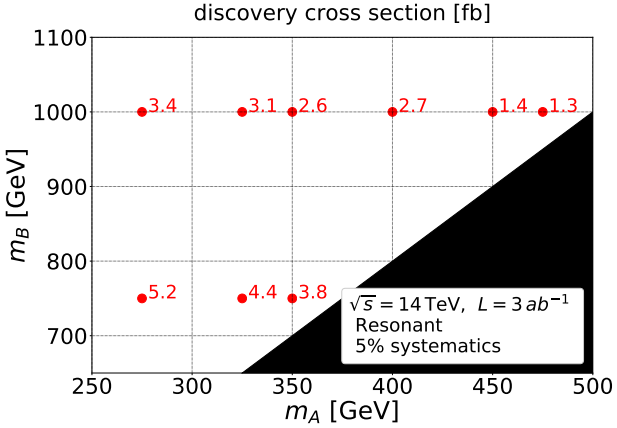
- Larger M_A
- Larger M_B
- Larger M_χ

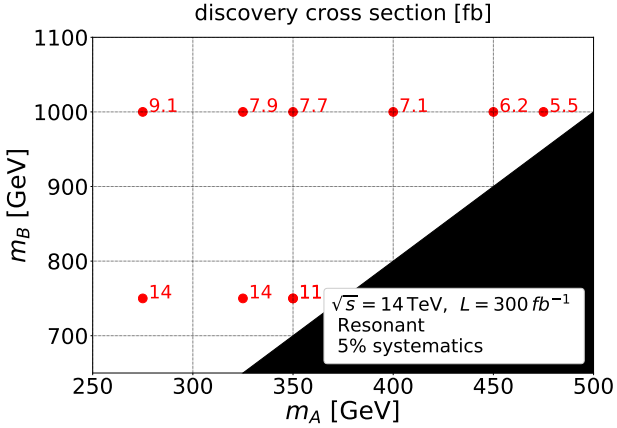


Resonant

- $2M_\chi < M_A$, M_χ irrelevant
- Very small production rate

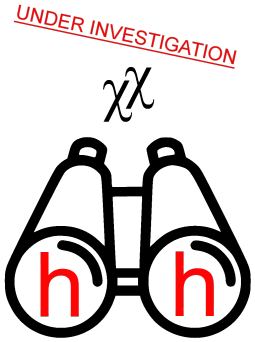






Not so visible at the HL-LHC

Conclusion



- Introduced 2 models with 3 new scalars
  - Couple to the Higgs sector
  - Lightest scalar is stable
  - Can be embedded into larger, complete models
- Symmetric model could be seen at HL-LHC
- Resonant model has a lower significance
  - Needs 2-10 larger cross section than our rate
- Can be a thermal relic in some parameter space